Ponon N, Appleby D, Mojarad SA, Kwa K, O'Neill A. Ferroelectrics for nanoelectronics. *In: Intel ERIC*. 2012, Dublin, Ireland.

Ferroelectrics for Nanoelectronics

Nikhil Ponon, Daniel Appleby, Shahin. A. Mojarad, Kelvin Kwa, Anthony O'Neill

School of Electrical Electronic and Computer Engineering, Newcastle University, United Kingdom

n.k.ponon@ncl.ac.uk

Summary

The material properties of thin film polycrystalline Barium titanate (BTO) and Titanium nitride (TiN) are being investigated for use in back-end-of-line (BEOL) and transistor gate stacks. The BTO was deposited by pulsed laser deposition (PLD) and rf-magnetron sputtering with TiN reactively sputtered for top electrodes. Results shows that TiN deposited at room temperature have reasonable quality and show a sheet resistivity of 219 μΩcm. The phase of polycrystalline BTO with grain size around 100 nm is found to be a mixture of cubic and tetragonal, resulting in changes to the expected ferroelectric properties of the thin film. BTO is also found to absorb CO_2 from the atmosphere forming a non ferroelectric thin layer of $BaCO_3$.

1 Introduction

BTO is a ferroelectric material which shows ferroelectric properties at room temperature. BTO could be used in the gate stack of a transistor to increase the switching speed and reduce the power consumption by potentially incorporating a phenomenon known as negative capacitance. This high-k material also shows nonlinear polarisation to an applied electric field making it suitable for tuneable capacitors in the BEOL metallisation of integrated circuits. Electrodes with low resistivity and perfectly engineered dielectric-electrode interface are necessary for achieving high quality metal-insulator-metal (MIM) capacitors. TiN is a material with thermodynamic stability, high work function and low diffusion. The material properties of BTO as well as TiN are discussed in this abstract in the view that they can be integrated to gate stack and BEOL.

2 Experiments and Results

TiN thin films were deposited using DC-magnetron reactive sputtering to investigate the potential of the material as a suitable electrode for BEOL MIM capacitors. The XRD spectra of the room temperature deposited TiN showed <111> as the preferred orientation. The sheet resistivity for these films were 219 μΩcm. Raman spectra showed titanium vacancies and nitrogen vacancies. The nitrogen vacancies showed a decreasing trend for increasing nitrogen partial pressure during deposition. TiN was successfully patterned in standard clean-1 solution using chromium as a hard mask, paving the way for use as top electrodes in the BTO MIM capacitors.

160 nm BTO were deposited using PLD and rf- magnetron sputtering on a platinum bottom electrode. X-ray diffraction (XRD) shows that BTO exists in a polycrystalline phase. Raman spectroscopy results further confirms that the material exists primarily in a cubic phase with a small presence of tetragonal phase, which accounts for the ferroelectricity of the material. The grain sizes estimated using XRD and atomic force microscopy (AFM) are around 100 nm. The non-existence of a tetragonal phase is due to the size driven phase transition phenomenon in ferroelectric materials. Below a critical grain size, ferroelectric materials change from a tetragonal phase to a cubic phase. A 4μm x 4 μm region was polarised using a conductive AFM tip. This region was then scanned using an electrostatic force microscope (EFM) tip to detect direction of polarisation. EFM images show non-uniform polarisation due to the polycrystalline nature of the film along with regions which are not at all polarised. These non polarisable regions correspond to cubic phases of BTO. These results also confirm the low intensity peaks corresponding to tetragonal phases as shown in raman spectra. The X-ray photoelectron spectroscopy results showed presence of surface carbonation. BTO is known for its ability to absorb atmospheric CO_2 and produce $BaCO_3$. This thin layer of $BaCO_3$ can act as a non ferroelectric layer in series with ferroelectric BTO, reducing the overall capacitance of the stack. Hence the deposition of BTO and electrodes without breaking the vacuum is crucial in achieving high quality interfaces.

3 Conclusions

TiN was developed as a potential candidate for electrodes in BEOL MIM capacitors. Polycrystalline BTO were also shown to exist in multiple phases. Grain size is very crucial in achieving ferroelectric properties of BTO. The surface carbonation can act as a dead layer and can degrade the electrical properties of the film.

Acknowledgement: We acknowledge Imperial College, London for providing PLD BTO.